

Inner Magnetosphere Effects

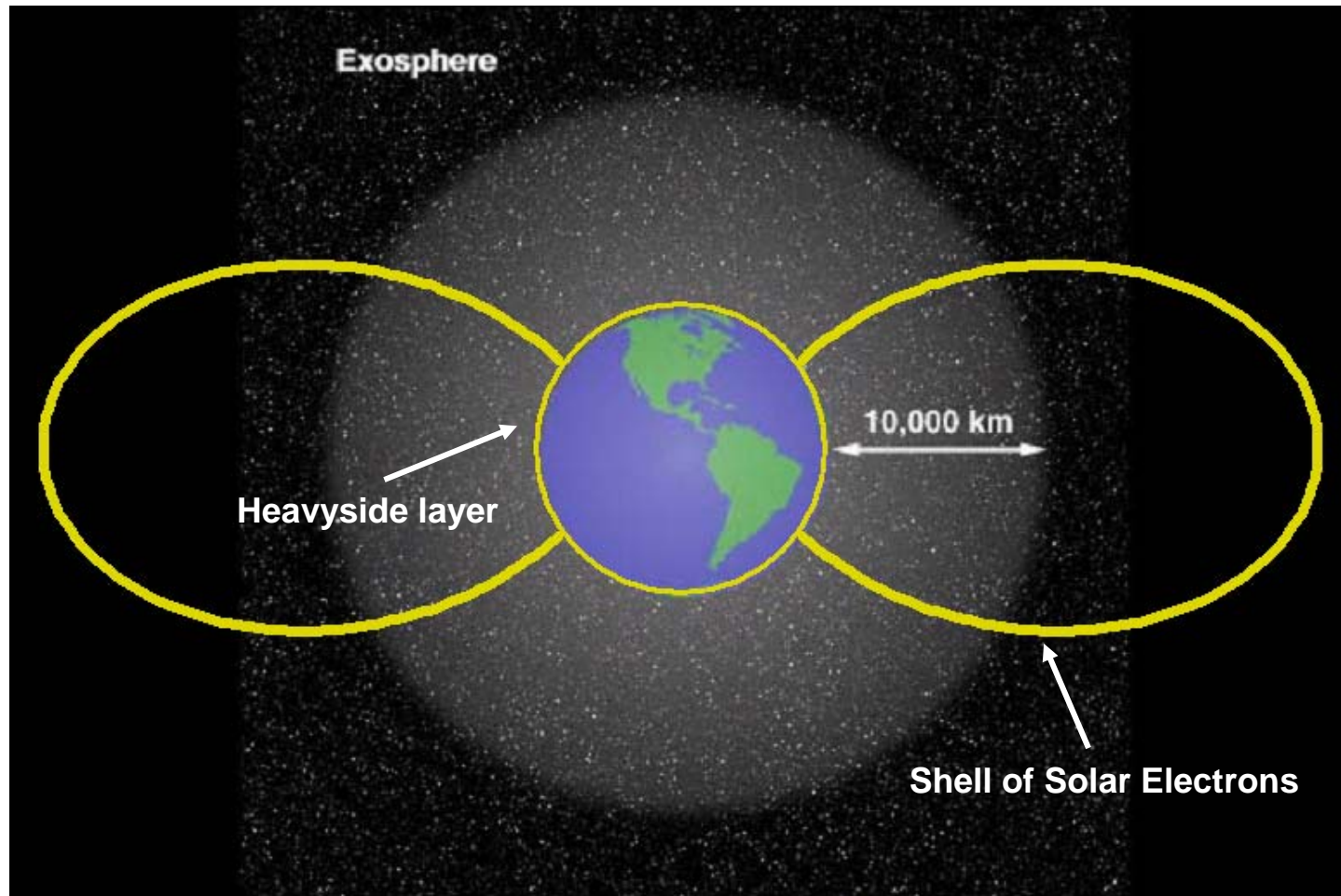
Roxanne Katus
Dennis Gallagher

Inner Magnetospheric
Effects:

Inner Magnetosphere Effects

- Historical Background
- Main regions and transport processes
 - Ionosphere
 - Plasmasphere
 - Plasma sheet
 - Ring current
 - Radiation belt
- Geomagnetic Activity
 - Storms
 - Substorm
- Models

Historical Background: Space in 1950



Inner Magnetospheric
Effects:

Historical Background

Historical Background

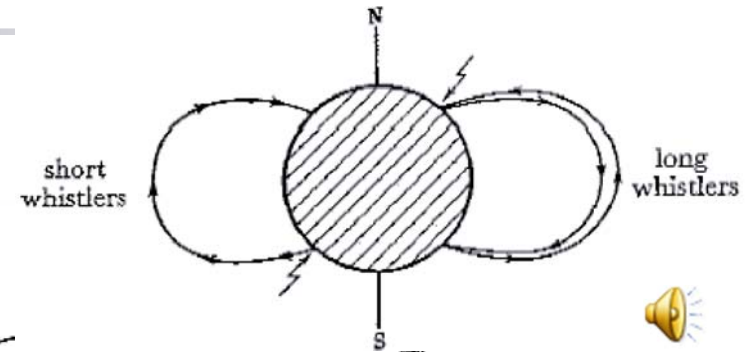
Whistlers revealed unexpected plasma



1952
L. R. Owen Storey
Cavendish Laboratory
University of Cambridge

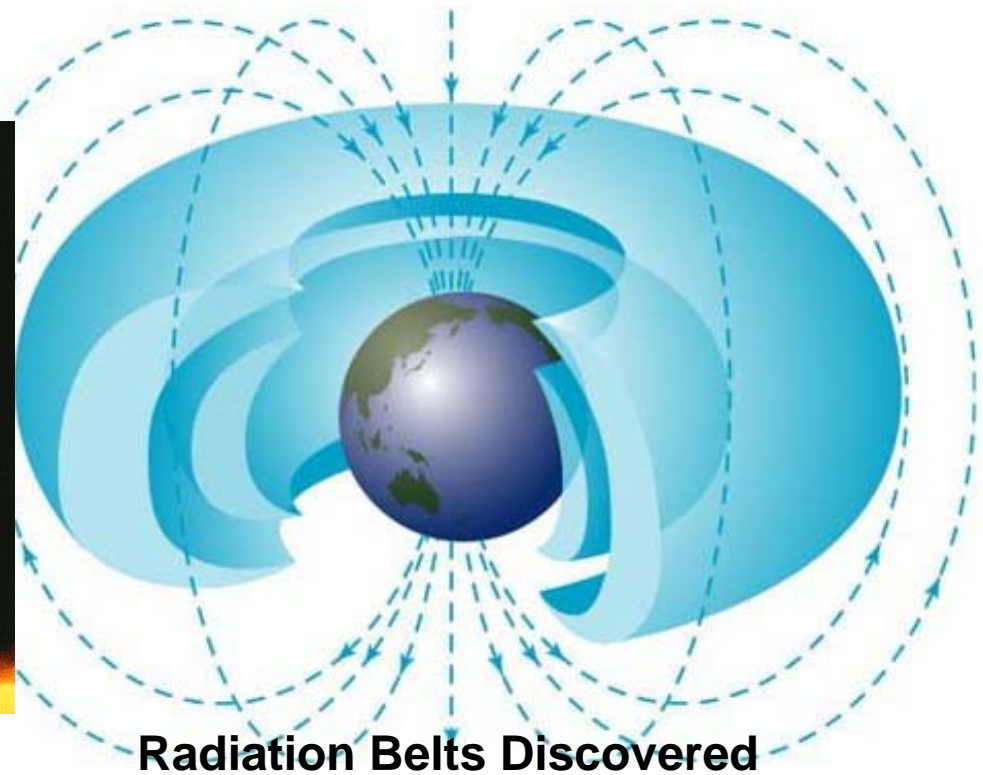
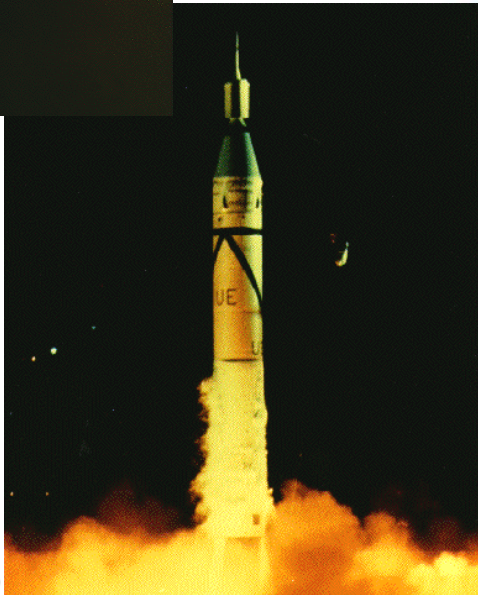
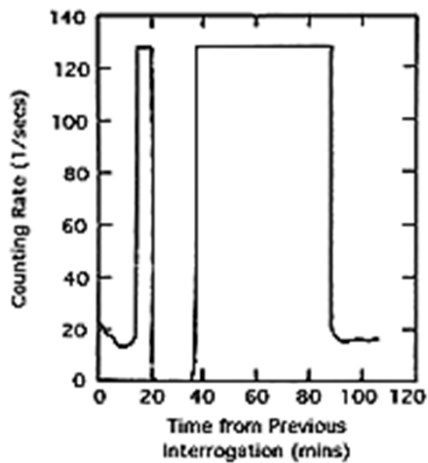
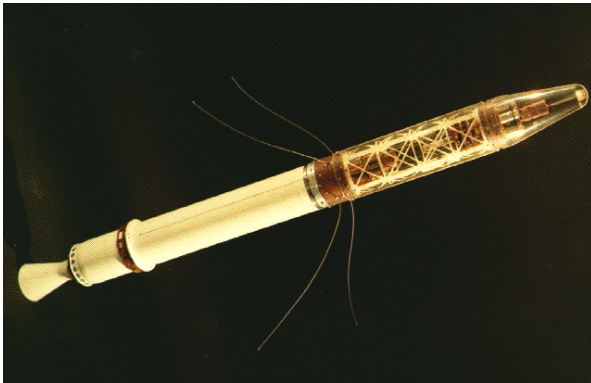
Inner Magnetospheric
Effects:

Historical Background



Historical Background

Explorer 1
January 31, 1958



Ionosphere

Photoionization



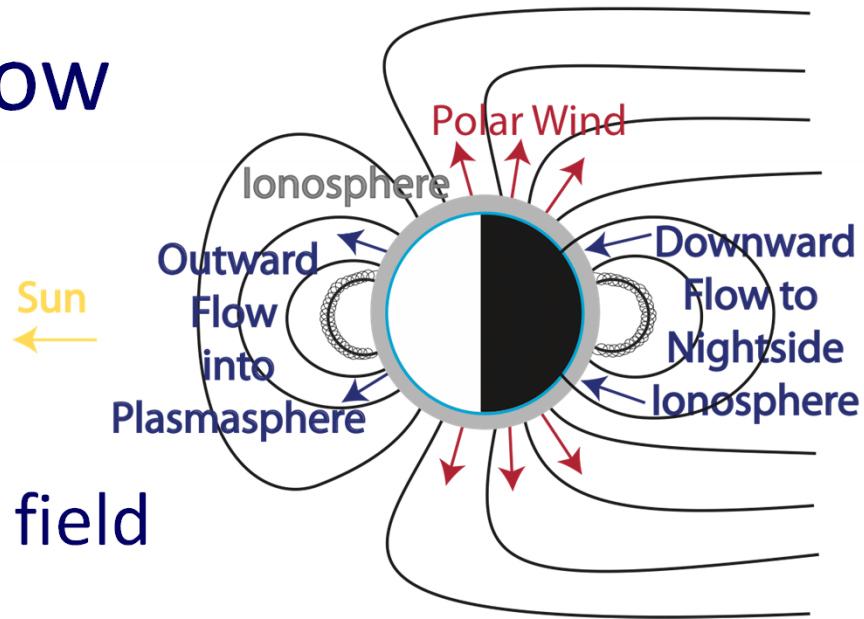
- Ionosphere: ionized portion of upper atmosphere
 - Extends from around 60 to beyond 1000 km
 - Completely encircles the Earth
 - Main Source: photoionization of neutrals
 - ✦ Other production processes may dominate in certain ionospheric regions
 - Loss Mechanism: ionospheric outflow

Inner Magnetospheric
Effects:

Main regions and transport processes

Ionosphere outflow

- Main cause
 - Ambipolar electric field
 - pressure gradients
 - Mirror force due to gyration of charged particles
- Polar wind: Ionospheric loss at polar latitude
 - Along essentially open geomagnetic field lines
- At mid-latitudes the plasma may bounce to the conjugate ionosphere or become the plasmasphere



Inner Magnetospheric
Effects:

Main regions and transport processes

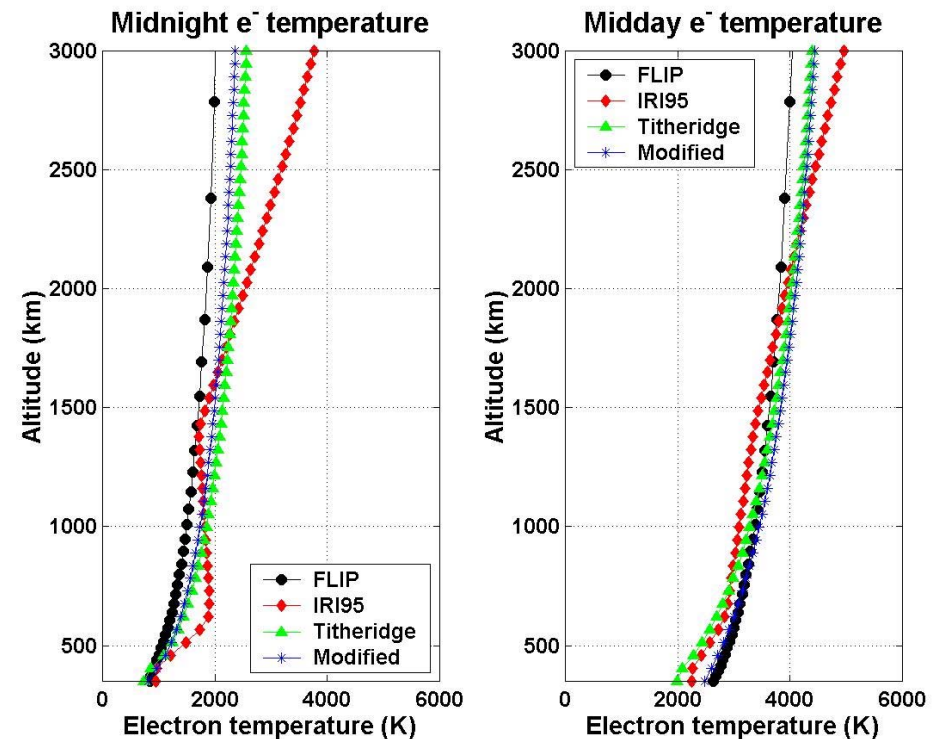
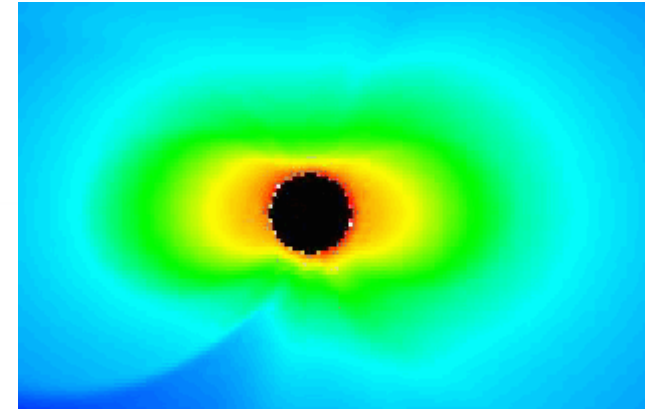
Plasmasphere Formation: Diffusive Equilibrium

$$H_j = \left(\frac{kT_i}{m_j g} \right) \left(1 - \frac{m_a T_e}{m_j T_t} \right)^{-1}$$

Titheridge (1972)

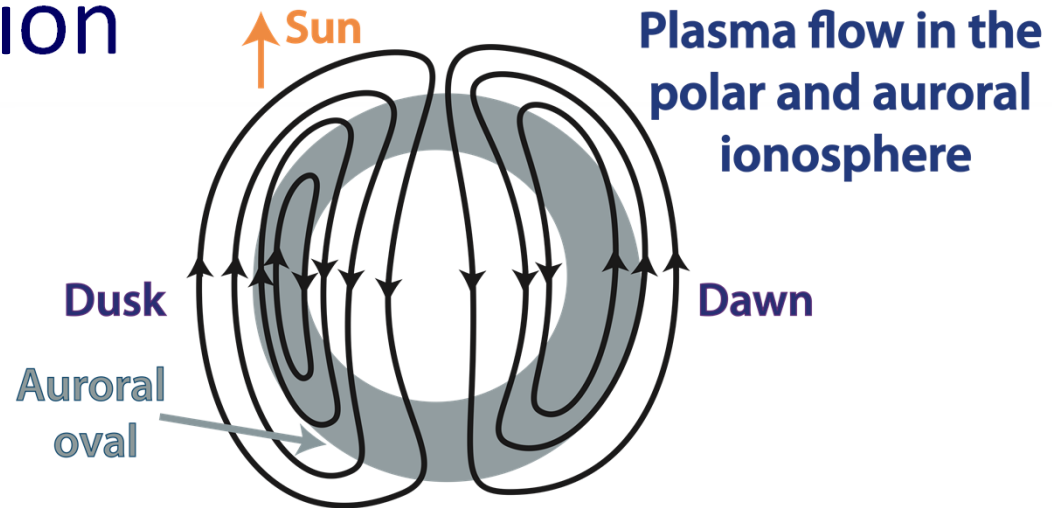
H_j = scale height
 k = Boltzmann constant
 m_j = j 'th ion mass
 g = gravitational constant
 m_a = mean ion mass
 T_e = electron temperature
 $T_t = T_i + T_e$ total temperature

Inner Magnetospheric
Effects:



Global convection

- In the Late 50s, ground-based measurements revealed the plasma flow pattern in the polar and auroral ionosphere
 - Anti-sunward flow over the polar cap and
 - Return flow equatorward of the auroral oval
- In 1959 Gold introduced the term convection
 - Resemblance to thermally driven flow cells



Inner Magnetospheric
Effects:

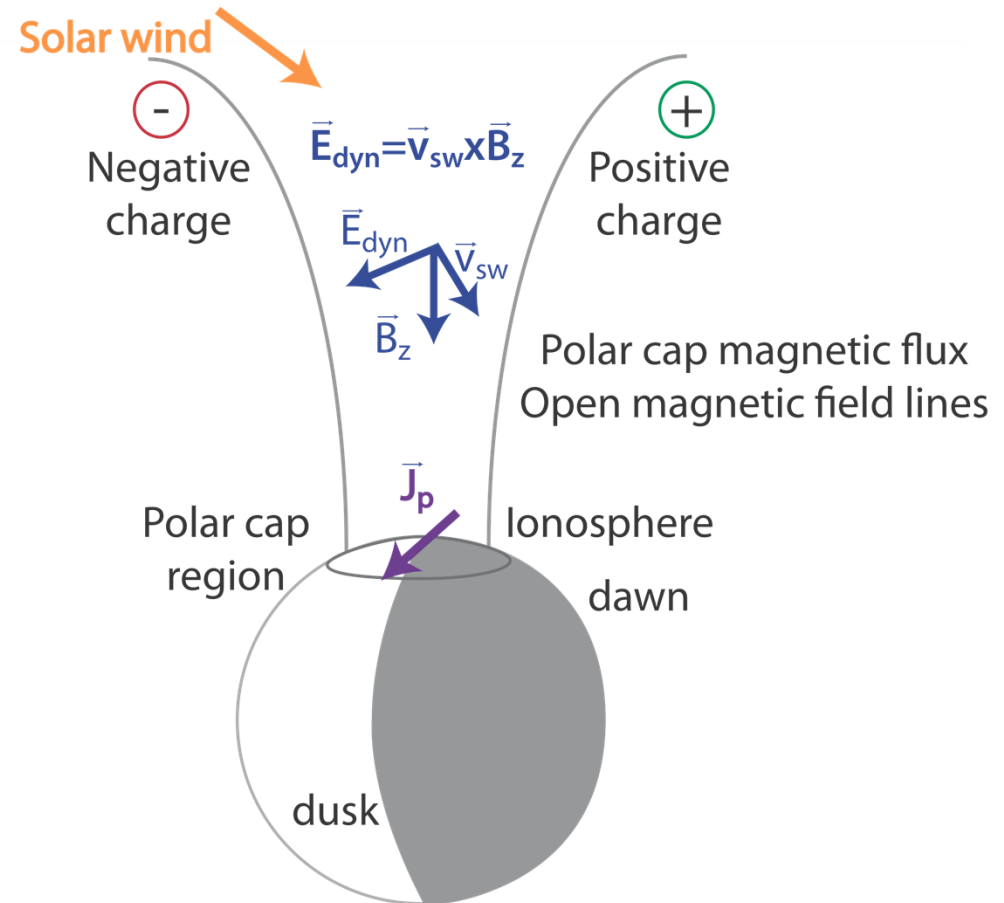
Main regions and transport processes

Solar wind dynamo

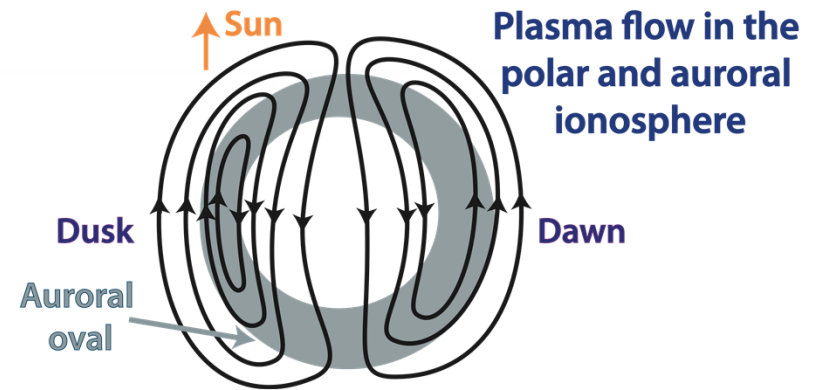
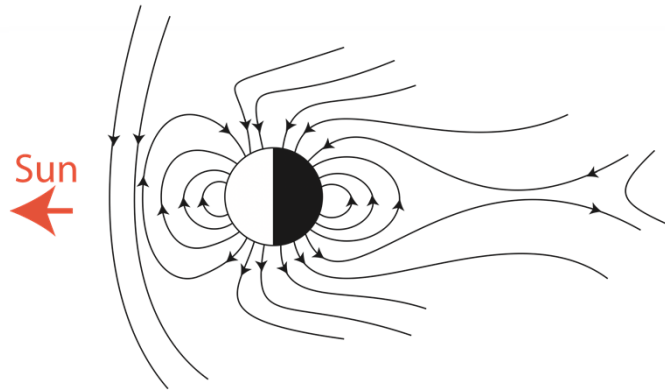
- Highly conducting plasma in the solar wind flows across polar geomagnetic field lines
 - Induces an electric dynamo field
 - Frozen-in flux concept

Inner Magnetospheric
Effects:

Main regions and transport processes



Reconnection

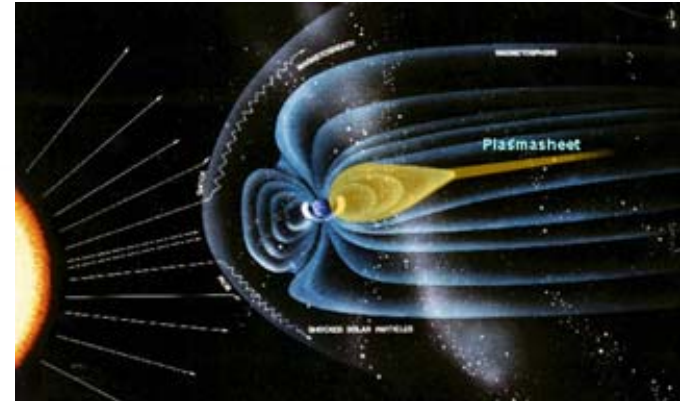


- If the polar geomagnetic field lines are open
 - The electric field produces an anti-sunward $E \times B$ drift of solar wind and magnetospheric plasma across the polar cap
 - Reconnection occurs down tail
 - Closed geomagnetic field lines flow back towards Earth at lower latitudes

Inner Magnetospheric
Effects:

Main regions and transport processes

Plasma sheet



- Plasma sheet: population of ionospheric and solar wind particles being accelerated Earthward
- Neutral current sheet: large-scale current flow from dawn to dusk across the plasma sheet
 - Separates the two regions of oppositely directed magnetic field in the magnetotail
 - Accelerates particles towards Earth
- Direct access to night side auroral oval
 - Can collide with ionosphere producing aurora



Inner Magnetospheric
Effects:

Main regions and transport processes

Adiabatic Invariants

- Energetic plasma near the center of the plasma sheet gyrates closer to the Earth

$$\mu = \frac{W_{\perp}}{B} = \frac{mv_{\perp}^2}{2B}$$

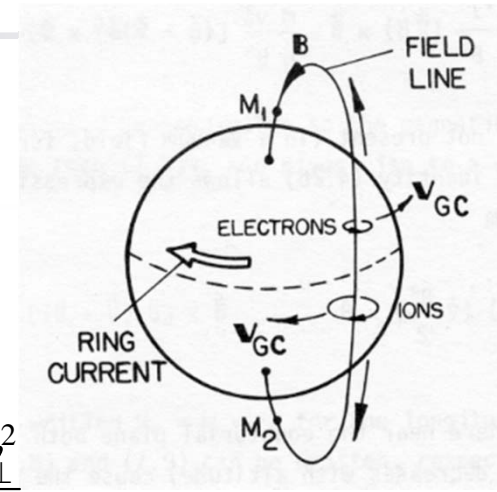
- Become trapped on closed dipole like field lines
- Encounter increasing magnetic field strength
- Bounce between hemispheres

$$J = \oint_{\text{bounce}} \mathbf{v} \cdot d\mathbf{l} = \oint_{\text{bounce}} v_{\parallel} dl$$

- Gradient and curvature drift

$$\Phi = \int_{\text{drift}} \mathbf{B} \cdot d\mathbf{A}$$

- ✦ Divert ions and electrons in opposite directions
- ✦ Form the ring current and radiation belts

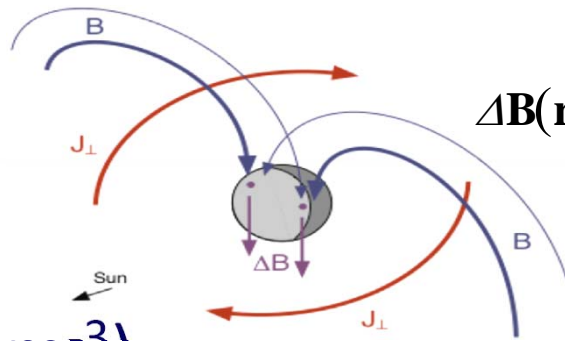


Inner Magnetospheric
Effects:

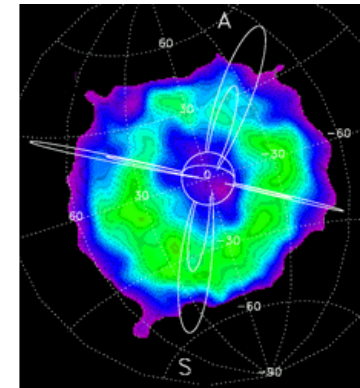
Main regions and transport processes

Ring Current

- Hot (1-400 keV)
tenuous ($1-10 \text{ s cm}^{-3}$)
- diamagnetic current produced
by motion of plasma trapped
in the inhomogeneous geomagnetic field
 - Torus-shaped volume extending from ~ 3 to $8 R_E$
 - Main Source: plasma sheet particles
 - Loss Mechanisms: charge exchange, coulomb collisions, atmospheric loss, pitch angle (PA) diffusion, and escape from magnetopause



$$\Delta \mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int_V \frac{\mathbf{J}(\mathbf{r}') \times (\mathbf{r} - \mathbf{r}')}{|\mathbf{r} - \mathbf{r}'|^3} d\mathbf{r}'$$



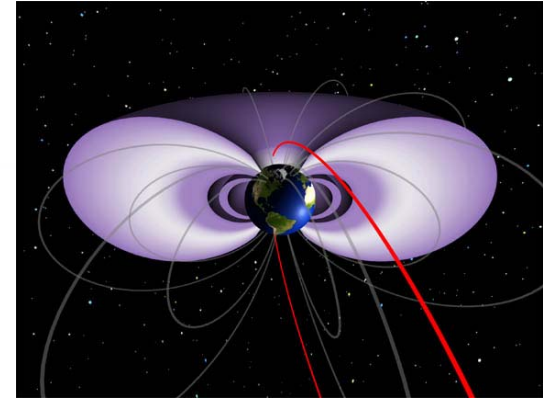
Chorus

Inner Magnetospheric
Effects:

Main regions and transport processes

Radiation Belt

- Very Hot (100s keV - MeV)
- Extremely tenuous: $\ll 1 \text{ cm}^{-3}$
 - Outer belt: very dynamic region
 - ✦ Mostly electrons located at 3-6 R_E
 - Inner belt: fairly stable population
 - ✦ Protons, electrons and ions at 1.5-2 R_E
- Source: injection and energization events following geomagnetic storms
- Loss Mechanisms: Coulomb collisions, magnetopause shadowing, and PA diffusion



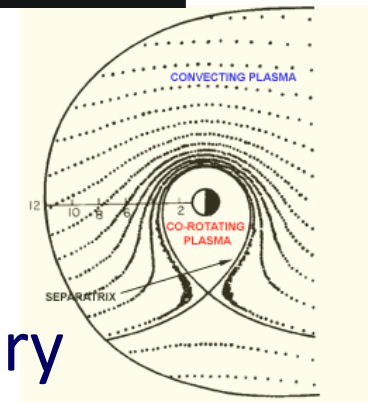
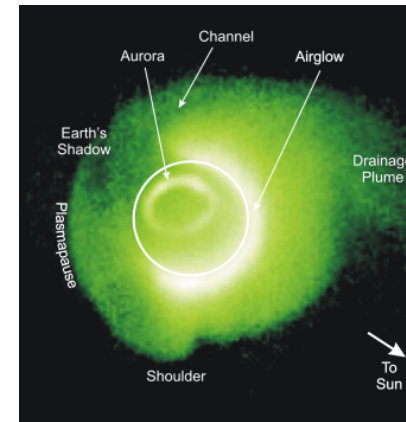
Hiss

Inner Magnetospheric
Effects:

Main regions and transport processes

Plasmasphere

- Cool (<10 eV)
- High density (100s-1000s cm^{-3})
- Co-rotating plasma
 - Torus-shaped, extends to $4-8 R_E$
 - Plasmapause: essentially the boundary between co-rotating and convecting plasma
- Main Source: the ionosphere
- Loss Mechanism: plasmaspheric erosion and drainage plume



Inner Magnetospheric
Effects:

Main regions and transport processes

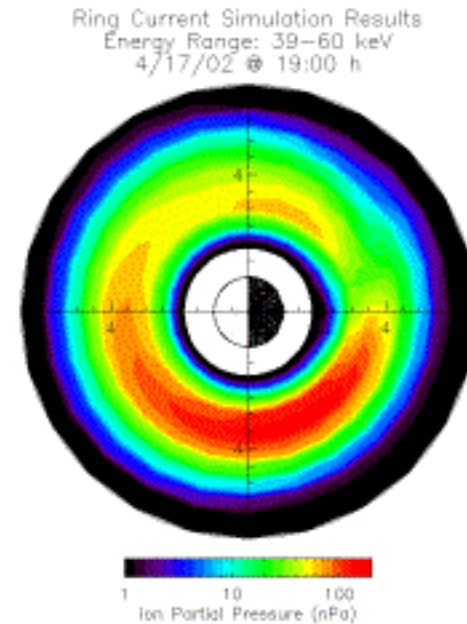
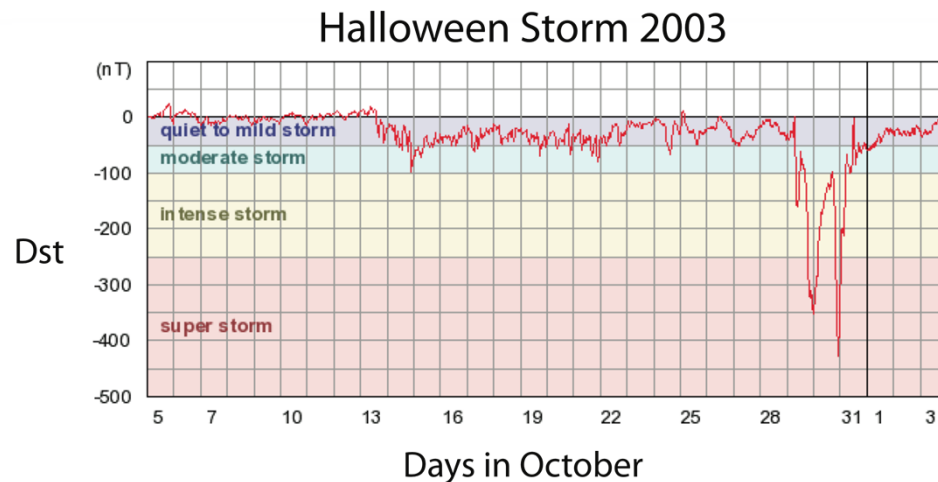
Geomagnetic storms

- Large (100s nT)
- Prolonged (days)
- Magnetospheric disturbances
 - Caused by variations in the solar wind
 - Related to extended periods of large southward interplanetary magnetic field (-IMF Bz)
 - ✦ Increasing the rate of magnetic reconnection
 - ✦ Enhancing global convection

Inner Magnetospheric
Effects:

Geomagnetic Activity

Geomagnetic storms



- Enhanced convection
 - Increased rate of injection into the ring current
 - ✦ The ring current then expands earthward
 - ✦ Induced current can reduce the horizontal component of the geomagnetic field (100s nT)
 - ★ Used to calculate Dst

Inner Magnetospheric
Effects:

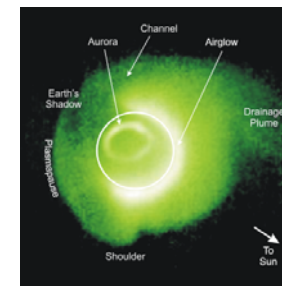
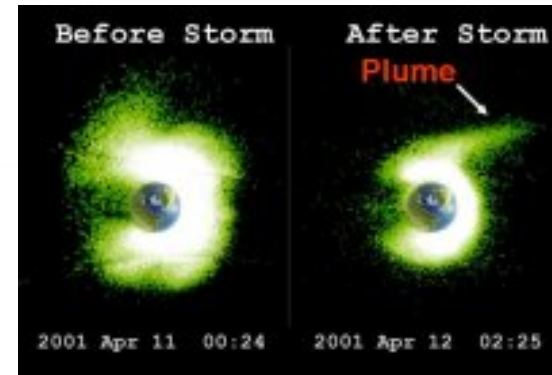
Geomagnetic Activity

Plasmaspheric Plumes

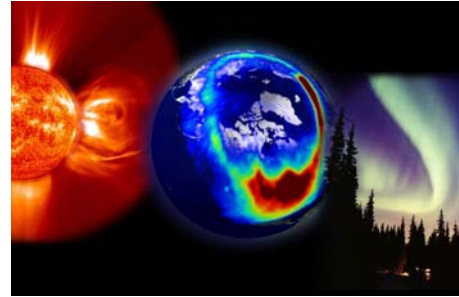
- Enhanced convection also causes the co-rotating plasmaspheric material to surge sunward
 - Decreasing the night-side plasmapause radius
 - Extending the dayside plasmapause radius
- Creates a plume extending from 12 to 18 MLT
- For continued enhanced convection less material remains to feed the plume and it narrows in MLT
 - Dusk edge remains almost stationary
 - Western edge moves eastward

Inner Magnetospheric
Effects:

Geomagnetic Activity



Substorms



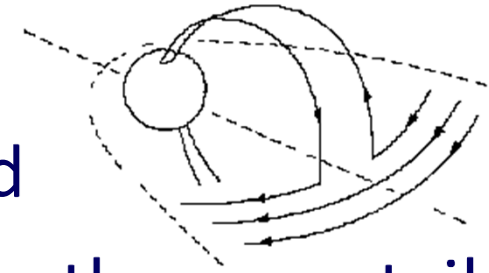
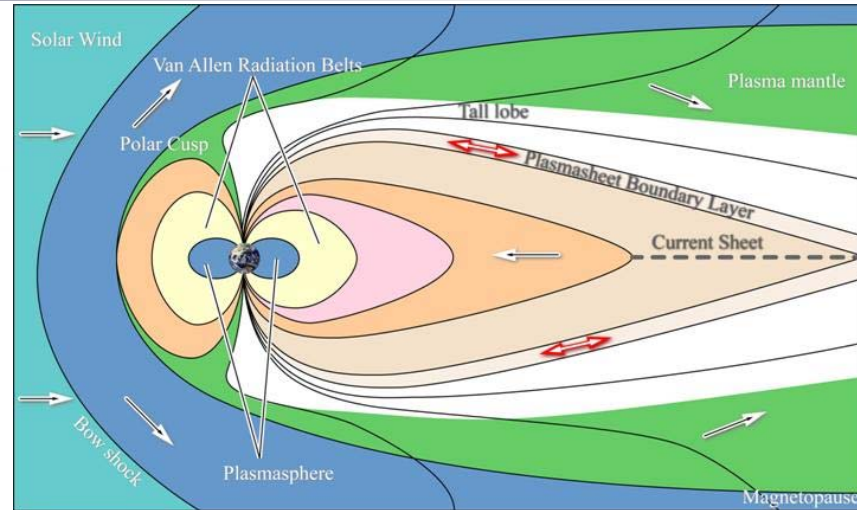
- A relatively short (hours) period of increased energy input and dissipation into the inner magnetosphere
 - Events may be isolated or occur during a storm
 - Associated with a flip from northward to southward IMF B_z
- Increased rate of reconnection
- Increased flow in magnetospheric boundary layer
- Energy accumulates in the near-Earth tail

Inner Magnetospheric
Effects:

Geomagnetic Activity

Substorms

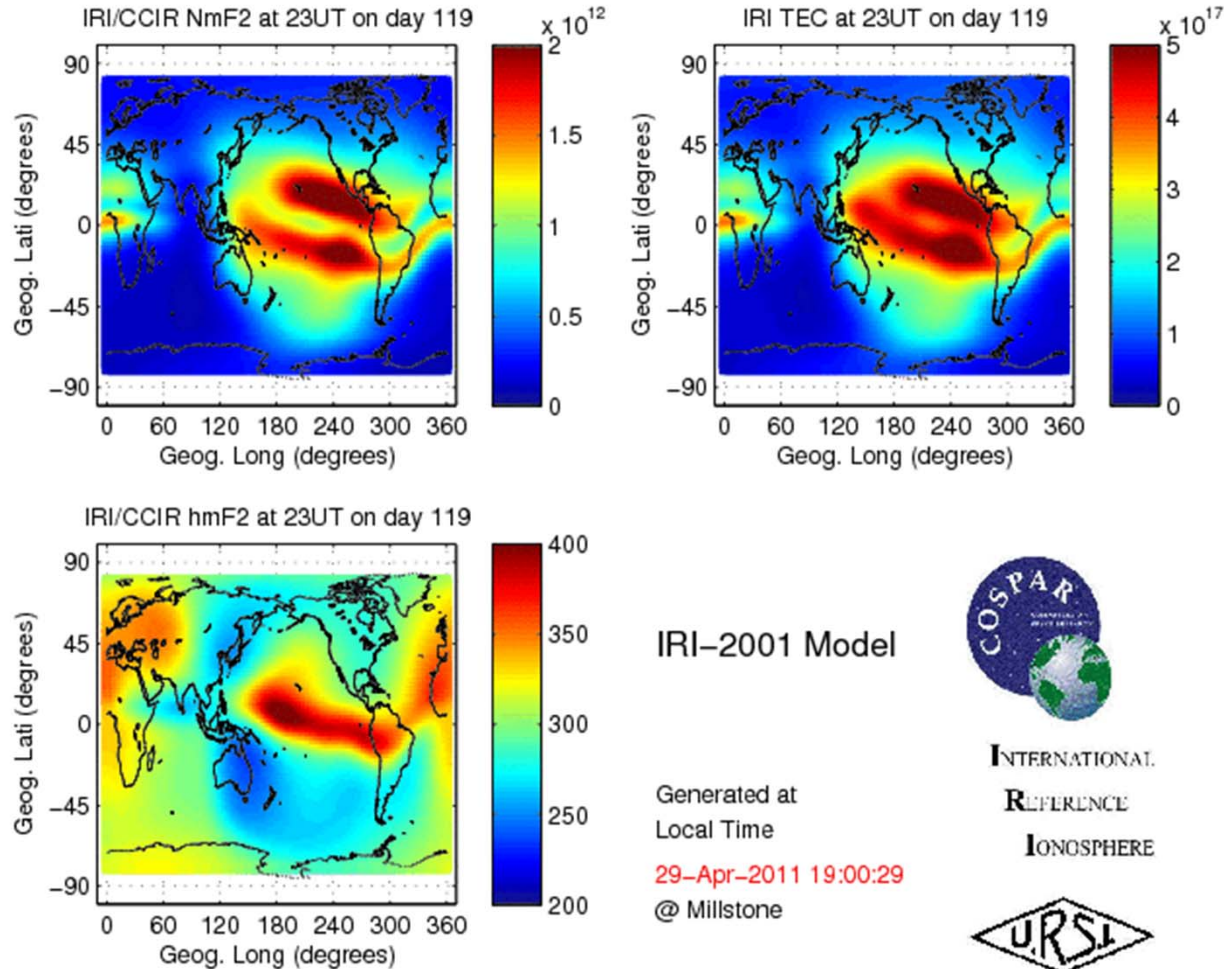
- Additional magnetic flux in the tail lobes causes the cross-tail current sheet thickness to decrease
 - When the current sheet thickness reaches its threshold reconnection occurs
 - The cross-tail current is disrupted
- The substorm current wedge closes the cross-tail current through the ionosphere
- Particle precipitation increases Auroral activity



Inner Magnetospheric
Effects:

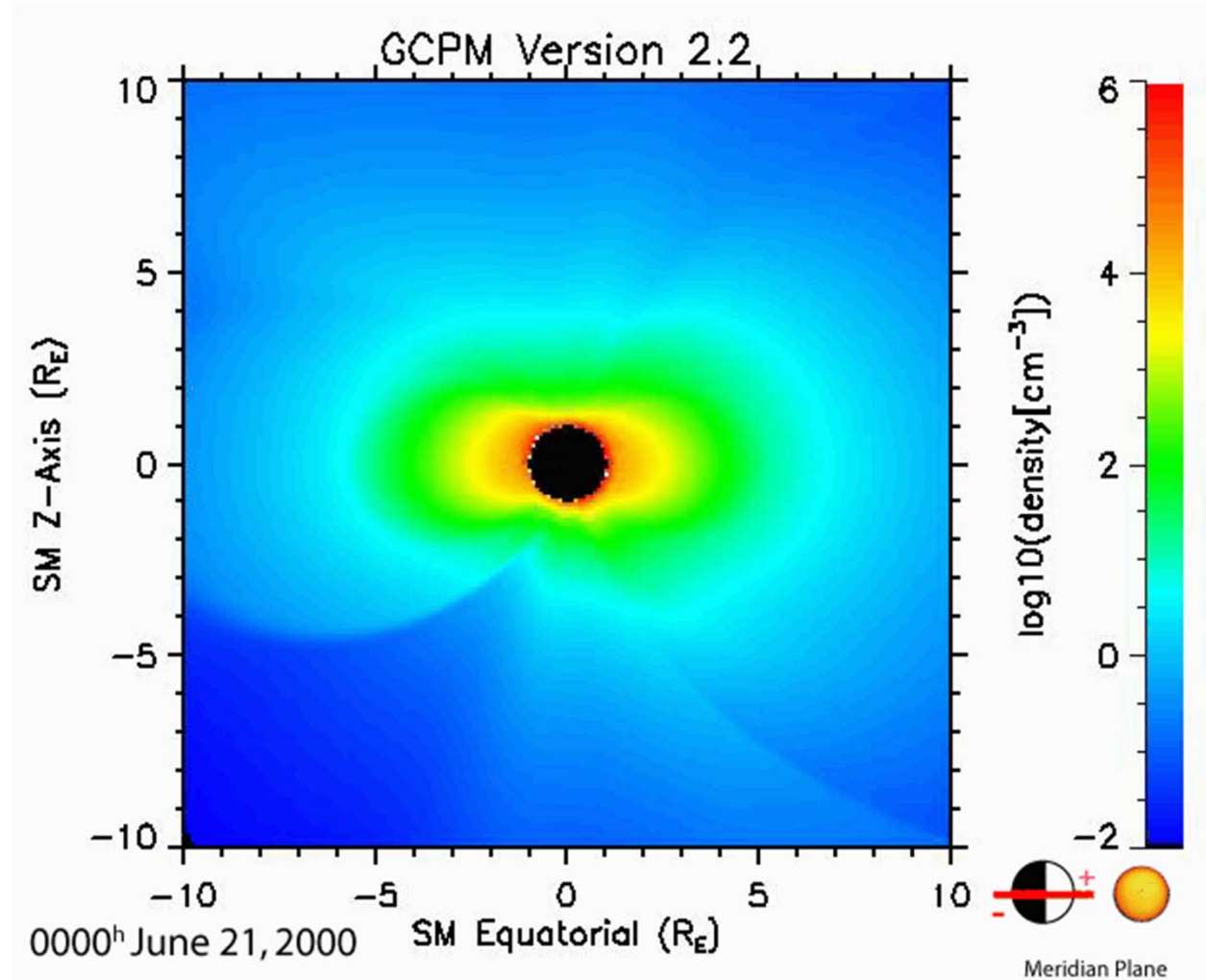
Geomagnetic Activity

Models – Empirical: IRI



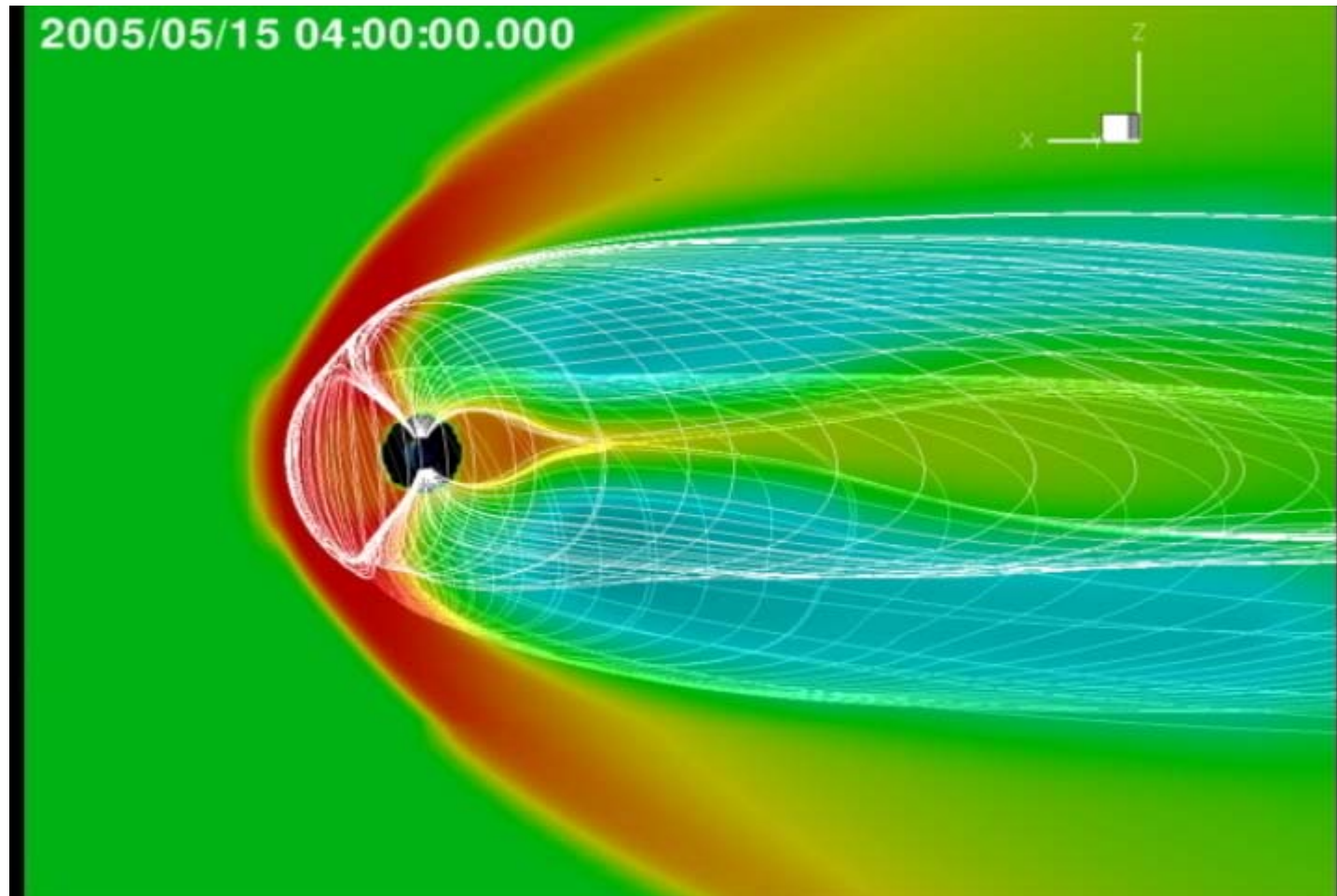
Inner Magnetospheric
Effects:

Models – Empirical: GCPM



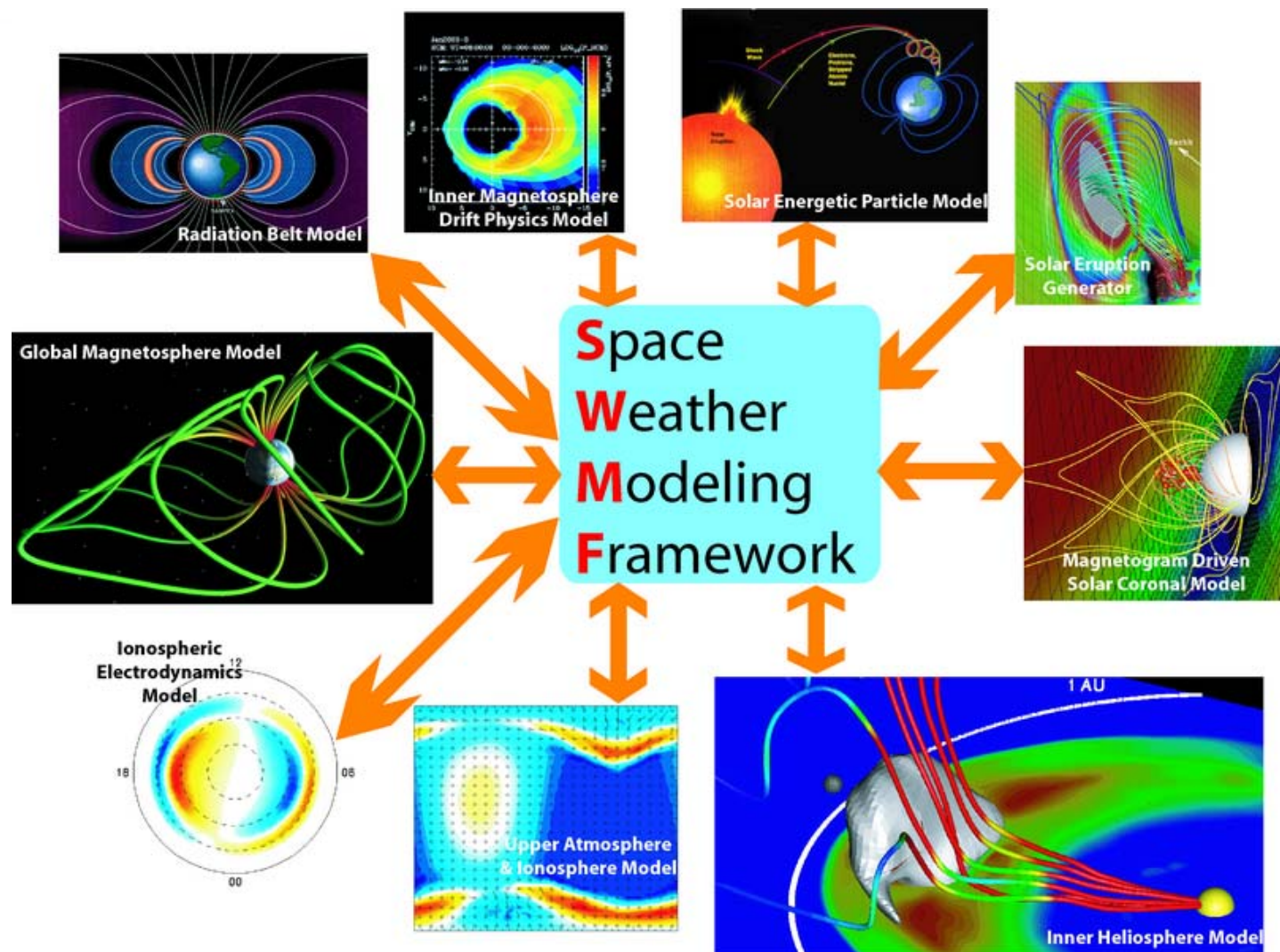
Inner Magnetospheric
Effects:

Models – Physics Based: BATS-R-US



Inner Magnetospheric
Effects:

Coupling Models



Inner Magnetospheric
Effects: